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THE AEROFLEX CORPORATION
AEROFLEX LABORATORIES DIVISION
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COPY 1 OF 1

9 May 1958
Refer to 04-586

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Dear Sir:

Enclosed you will find the original and one copy of a report of the Aeroflex Laboratories Engineering Staff on the HR-73C Configuration.

We trust this will be of help to you in evaluating the equipment.

Very truly yours,

THE AEROFLEX CORPORATION
AEROFLEX LABORATORIES DIVISION

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Assistant Chief Engineer

TT/ajs
Enclosure:
Copy 1 and 2 of report.

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Report on the HR-73C Configuration

Before reporting on the opinions reached on the HR-73C configuration, it is well to consider some of the limitations of these opinions. The opinions are based on a few hours visual observation of the equipment and a similar time spent discussing it. On the basis of such brief acquaintance, one would not normally wish to do more than perhaps suggest a line of attack for study. Time limitations prevent the instrumentation and testing that would be desirable before arriving at more definite conclusions. The Aeroflex Corporation has, however, had the benefit of 7 or 8 years of concentrated work on camera mount systems of a very great variety and has successfully encountered and solved many problems in this field. We have constructed mounts for cameras of masses greater than that encountered here; we have also used, on occasion, the "rate gyro steadied system" with HIC-5 gyros (which is the system used in the HR-73C configuration). On the basis of this experience we believe that the comments contained in this report can be given greater weight than would ordinarily be justified by our brief acquaintance with the configuration.

The comments will be divided into three categories: 1) Opinions as to the probable major sources of trouble in the present system. 2) Suggestions for possible solution within the time span allotted. 3) Suggestions for redesign to ensure proper results and estimates of time to accomplish these improvements.

1. Major Sources of Trouble. There seem to be a number of areas where seriously deleterious motion of the axis may be introduced. Roughly in order of their importance:

a) By far the most important source of trouble is the lack of rigidity of the system. This lack of rigidity can deteriorate the system in several ways depending upon exactly where the compliances are located. It is to be emphasized that we are here concerned only with the steadiness effects and not with the optical effects introduced by the vibration of individual optical elements. There are three essentially different effects to be considered depending on the location of the compliance.

First, and most serious are the relatively large masses which are attached to the stable element by rather soft supports. In an ambient vibration field this can be extremely deleterious to steadiness. The major principle involved in a mount system of this sort is to maintain the center of gravity precisely at the center of rotation. This is accomplished by carefully balancing the mount under static conditions. Figure 1 shows the situation diagrammatically. Under static balance, the center of gravity of the system composed of M_1 and M_2 lies on the center of rotation. If the support is now allowed to vibrate at a low frequency, no rotation results. As the frequency increases, however, it reaches the natural frequency of the spring mass system and finally passes it. At high frequencies, the smaller mass M_2

will be almost stationary while the main mass moves with the support. Dynamically the system is out of balance by an amount equal to $M_2 \times d$ (the distance from the c. g. of M_2 to the support). A rotation of M_1 therefore results. All the effort expended in balancing the stable element has been wasted if large masses are not rigidly coupled to the main body. A number of such departures from good practice were noted, by far the worst being the electronics rack.

Compliances in the structure also affect the servo system stability. The most serious effect of this sort occurs when compliance is introduced between the solenoid and the gyro. Unfortunately this compliance is rather large in the HR-73C configuration. It appears to arise principally in the brackets holding the solenoid and in the brackets transmitting torque from the solenoid armature. However, it is also partially due to compliance in the rather lengthy structure between the torque brackets and the gyro support.

The last effect is that of large masses coupled to the solenoid-gyro system through a spring. While less destructive than the previous situation, this can cause instability in the servo also.

The effect of this lack of rigidity and the resulting instability is to limit the system to abnormally low gain values, permitting the residual disturbances coupled into the system by aircraft motions to create abnormally high unsteadiness.

b) Another large source of trouble in the system is the effect on the system of sources of vibration in the configuration. The gyros are apparently generating some of this noise. Also at fault is the programer and the shutter assemblies. These are quite close to the gyro assembly and couple vibration into the gyro. This causes the solenoids to disturb the system also since in general the feedback is not operative at the frequencies involved.

c) I believe that the caging system is another serious source of trouble. Although the shock excited vibrations appear to the eye to damp out quickly, I believe that enough residual vibration remains to disturb the system. Experience on our own equipment shows that the inherent damping varies very greatly with the oscillation amplitude. Thus while oscillations of magnitude large enough to be apparent to the eye die out rapidly, the damping decreases as they die out. When they are quite small, the damping is often almost negligible yet the amplitude may be still severe enough to affect resolution without being apparent to the eye.

d) Turning now to consideration of the servo system, let us comment briefly on the suitability of the rate gyro steadied system. An alternative system is to slave the mount to a positional gyro. Both of these systems have their gains limited by the compliances in the system rather than by any of the theoretical factors. Experimentally, we have found that the effective system cut-off frequencies must be held to the same value (a value sufficiently low so that the natural frequencies of the spring-mass elements are well above the cut-off) in order to retain stability.

It can be shown (analysis available on request) that the rate gyro system cut-off must lie near a frequency given by

$$W_r = \frac{K_R}{J} \qquad \text{.....................(1)}$$

where W_r = angular cut-off frequency for rate system
K_R = Rate gain (torque per unit rate)
J = System inertia

Similarly the cut-off frequency of a positional system must lie near

$$W_p = \sqrt{\frac{K_P}{J}} \qquad \text{.....................(2)}$$

where W_p = Angular cut-off frequency for positional system
K_P = Positional gain (torque per unit angle)

Now these two would be set by the rigidity limitations to about 10 cps or somewhat less. Thus:

$$W_r = W_p = 60 \qquad \text{.....................(3)}$$

Now at very low frequencies the response of the two systems to a disturbing torque may be given by:

$$\theta_P = \frac{T \sin wt}{K_P} \qquad \text{.....................(4)}$$

$$\theta_R = \frac{T \sin wt}{K_R W} \qquad \text{.....................(5)}$$

Now the value of K_P from (3) and (2) may be substituted in equation (4) and similarly for equation (5).

$$\theta_P = \left(\frac{T}{J} \sin wt\right) \frac{1}{3600}$$

$$\theta_R = \left(\frac{T}{J} \sin wt\right) \frac{1}{60\ W}$$

It is apparent from the above relations that the positional system is superior for low frequency disturbing torques such as these introduced by the roll, pitch and yaw of the aircraft. The exact relations are modified somewhat by the provision of stabilizing networks and other system details, but not by a sufficient amount to affect the conclusion based on the rough analysis above.

e) It is understood that the introduction of vibration isolators between the base and the aircraft resulted in instability. This can only mean one thing. There must be a sizeable amount of coupling between the base and the stable element. It did not appear that this could be caused by the wiring and tubing which cross the axes. The most probable cause of restraint lies in the solenoids. These are capable of two types of restraint, that due to positional torques (due to end effects in the solenoid, hysteresis in the iron, slot and coil effects depending on exactly how the solenoids are wound). The other source of restraint is the viscous restraint produced by eddy currents when the armature is moved (experience shows that unless the design gave specific attention to this effect, it would be large enough to cause trouble in a stabilized mount). If these restraints could be eliminated, as they are in the Aeroflex torquer design, it is believed that isolators could be used to advantage.

2. Suggestions for Improvement of Present Designs. The time period available to correct the troubles suspected above is too short. However, some of the items can be advantageously handled in a short time. These are:

a) It appears from a superficial examination at least, that many of the items now on the stable element could be removed. The electronics rack and the programmer could be packaged in a chassis and mounted elsewhere. These two seem to be primary sources of the trouble described in paragraph 1.a and 1.b foregoing.

b) The system could be changed to a positional system by adding data takeoffs in the roll and yaw axes and feeding the three positional signals into the HIG torquers. The spring amplifiers would then be eliminated or used to amplify the positional signals for the gyro torquers. Such a system could be set up using the same major components that presently exist, but changing the electrical circuitry somewhat. Introduction of IMC would occur by switching out the positional signal in pitch and applying a constant voltage to the pitch gyro torquer sufficient to precess the gyro at the desired rate. The mount would then follow the gyro. The practicality of this suggestion should be more thoroughly analyzed, first by more detailed estimate of the changes and time required for them and, second, by analysis of expected aircraft motions to ensure that the gyro zeroing gain can be made low enough to obtain steadiness and yet be high enough to avoid hitting the stops too frequently. The stop settings of ±2° are rather low for anything except careful flying in a stable ship. The changes suggested here would help overcome the problems outlined in paragraphs 1.c and 1.d.

3. Suggestions for New Design. The previous suggestions can be confidently

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expected to improve the results but whether the improvement will be adequate is very difficult to determine without detailed study and measurement. Adequate results could be ensured by a redesign which would take 8 - 12 months. The suggested areas for redesign would be:

a) Elimination of all non rigid attachments, mounting all electronics and auxiliary equipment off the stable element.

b) Useof the Aeroflex Vertical gyro which would give a reference with no vibration, and with a clean signal capable of good signal to noise ratio to fractions of a second. This gyro would also require less electronics in the system.

c) Use of the Aeroflex Torquer drive which would eliminate objectionable coupling from base to aircraft.

d) Use of vibration isolation of the entire system. This would be possible if the Aeroflex torquer were used.

e) Use of bearings instead of the crossed spring supports. We believe that well designed bearings would give adequately low friction and would enable us to widen the stop limits to ±8°. This would permit the gyro and positional servo system to be slaved to vertical instead of to the aircraft as in paragraph 2.b. The result of such a system would be improved steadiness and verticality.

f) More rigid coupling of torquers to the gyroscopes. This, too, is rendered more practical by the use of a bearing type of support.

g) Use of a Minneapolis Honeywell HIG4 gyro in the yaw axis. This gyro does not have the large vibration and rumble components that the present gyros apparently have. We have used these HIG4's for systems of this sort before with excellent results.

h) Elimination of periodic caging and substitution of IMC and positioning by the mount servos and gyro (as in paragraph 2.b).

i) More rigid gyro support and coupling to camera. We note the erroneous use of kinematic design principles in several places in the structure (example: the gyro assembly. The three gyros are mounted to a quite rigid structure which is then tied to the stable element through 3 mounting points. While kinematically correct, this design misses the point. When gyros are used as null sensors on a stable element it is not necessary to maintain their orthogonality with any great precision. The weight of the rigid gyro brackets could have been better used if it were incorporated into the structure more closely. These brackets could be used to rigidize the entire tie between the gyros and the rest of the system). Rigidity is more important than stress or distortion throughout the structure. This being the case, kinematic principles should be ignored in many areas to give better rigidity, i. e., tie things together with as much redundant restraint as possible.

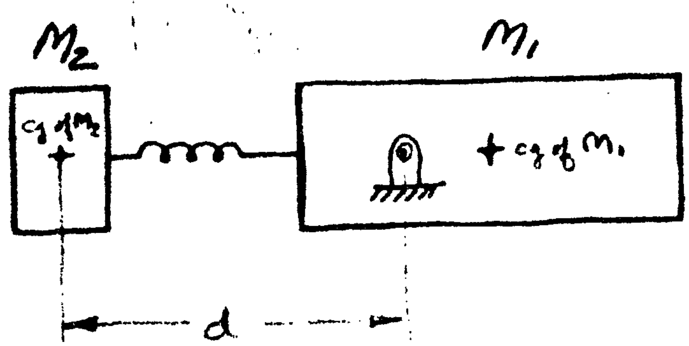

FIGURE 1